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Performance evaluation of an agricultural residue-based modular throat-type down-draft gasifier for thermal application

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ABSTRACT

A 125 kg h^{-1} biomass gasifier of modular design was developed at the Sardar Patel Renewable Energy Research Institute (SPRERI) and tested on the thermal mode to test the concept. Based on these studies, a scaled-up 375 kg h^{-1} modular throat type, down-draft gasifier system was designed, developed and tested. The performance of the two systems is discussed in this paper.

The smaller gasifier when tested at a wood consumption rate of 55 kg h^{-1} gave a gas calorific value of 4.24 MJ N m^{-3} and cold gas gasification efficiency of 63%. The larger gasifier system was operated for about 50 h using agro-residues briquettes at gas flow rates of 213 and $278 \text{ N m}^3 \text{ h}^{-1}$. The cold gas efficiency was in the range of 70–73%. The gasifier was also operated at a gas flow rate of $460 \text{ N m}^3 \text{ h}^{-1}$ using wood as feedstock at a cold gas efficiency of 71%. The gasifier system was also tested continuously for 10 h without any problem and it produced good quality of gas consistently.

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1. Introduction

The presently used down-draft gasifiers have circular throats, which have to be dimensioned separately for each capacity of design. In addition, these gasifiers have not performed satisfactorily in the size range of more than 250 kg h^{-1} . This happens because air cannot travel up to the center of the gasifier system and between the air tuyeres, which creates hot and cold spots inside the gasifier during operation, resulting in incomplete tar cracking and high tar content in the gas [1].

To overcome the above-mentioned problem, the Sardar Patel Renewable Energy Research Institute (SPRERI) has designed, developed and tested a modular throat-type down-draft gasifier having a rectangular throat, with suitably

rounded corners to ensure uniform gas flow across the reactor section.

In this design, the throat of the gasifier has square shape (module of $260 \text{ mm} \times 260 \text{ mm}$). A larger capacity gasifier can be designed by adding modules in series, thus yielding the throat of a larger gasifier with rectangular shape ($260 \text{ mm} \times 780 \text{ mm}$) (see Fig. 1). Thus, the modular gasifier offers the advantages of low tar gas and overcomes the capacity limitations of circular throat-type gasifiers [1].

The design was patented by SPRERI [1]. The design is compact and can convert up to 625 kg of biomass per hour. A gasifier based on this design can be very useful for industrial application in small and medium boilers and for internal combustion (IC) engines after cleaning the producer gas through a cooling and cleaning system.

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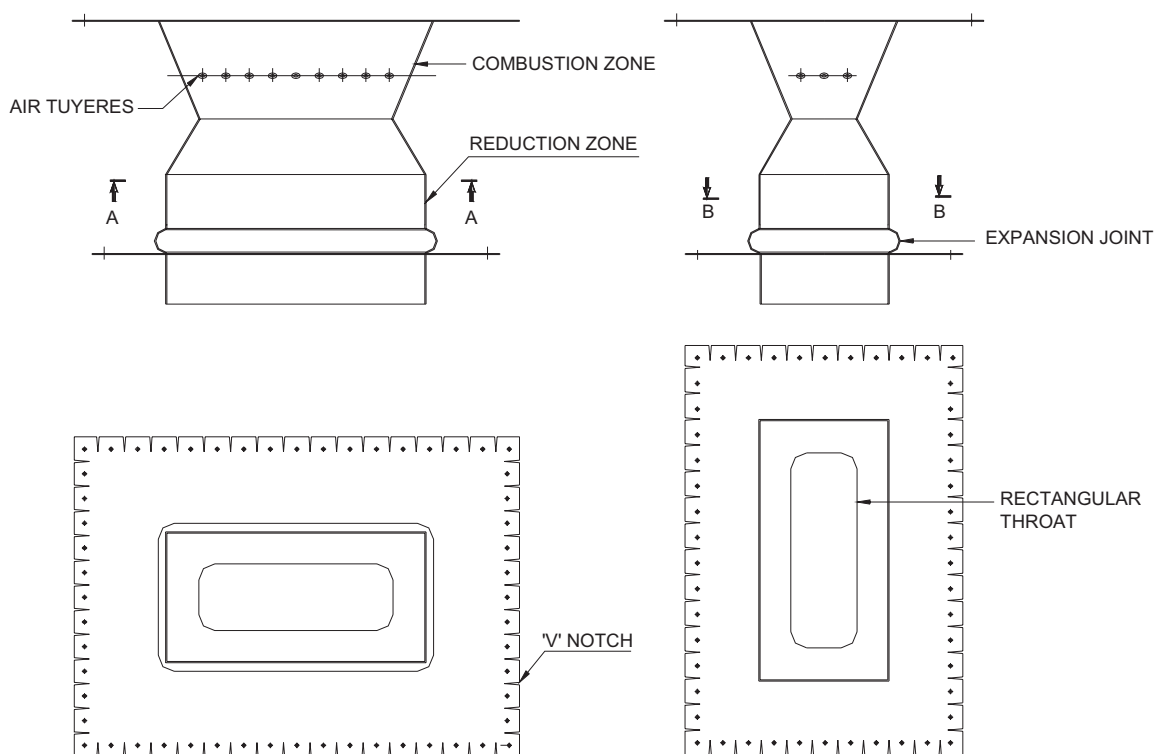


Fig. 1 – Schematic diagram of a rectangular throat of modular down-draft gasifier [1].

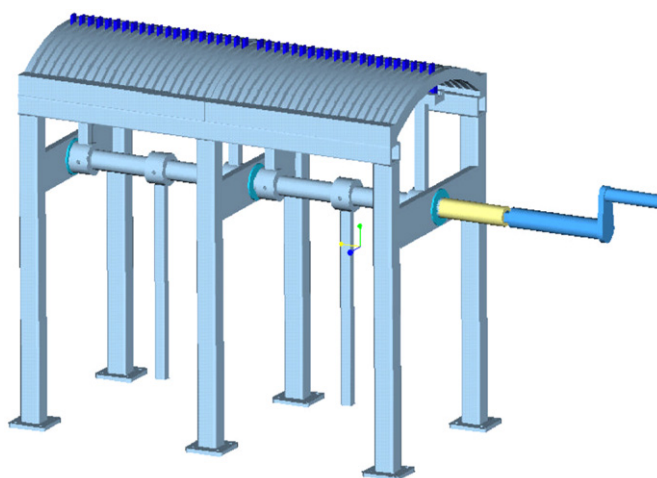


Fig. 2 – 3 Dimensional view of a comb-type grate.

2. Materials and methods

2.1. 125 kg h⁻¹ modular down-draft gasifier

Initially, a 125 kg h⁻¹ modular gasifier system was designed, fabricated and installed at the institute to study its feasibility. The gasifier consists of a square reactor with suitably rounded corners, cyclone, control valve, blower and burner. The gasifier had a throat of 260 mm × 260 mm and a matching hopper. The hopper was made from stainless steel 304, while

the throat and reduction zone were fabricated from stainless steel 310.

The initial trials of the system were taken using sized wood as fuel. It was found possible to ignite and operate the gasifier in the same way as a circular gasifier. The comb-type hand-operated grate (see Fig. 2) was used to remove ash.

It was observed that the grate was not working when the gasifier was loaded. Its teeth had to be shortened and reduced in number to make it work satisfactorily. During the experiments, it was also observed that the welding at the throat was destroyed. The crack found in the throat was due to two main

reasons: first, uneven expansion due to the square shape of the throat and, second, the converging and diverging portions of the reactor were welded in square frame so that there was no space for vertical expansion. The problem was solved by using an expansion joint in the reduction zone (see Fig. 1). Distortion was also found in the matching flanges of the hopper and reactor due to uneven expansion due to its square shape. The problem was solved by cutting a V slot in between the bolts (see Fig. 1).

A series of trials with wood were carried out on the gasifier. During one trial it was observed that, at a wood consumption rate of 55 kg h^{-1} , the gas calorific value was 4.24 MJ m^{-3} and cold gas gasification efficiency was 63%.

Table 1 – Technical specifications of the 375 kg h^{-1} modular gasifier system

(A) Gasifier	
Rated capacity	
1. Thermal (MW)	1.39
2. Electrical (kW)	400
Rated gas flow rate ($\text{Nm}^3 \text{ h}^{-1}$)	1000
Types of feeding system	Batch type
Feed stock	Briquettes
Hopper capacity (kg)	900
Ash removal unit	Manual
(B) Producer gas burner	
Type	Aerated, jet type
Flame port area (mm^2)	7850
No. of port	Single

This gasifier was also used to conduct trials to develop an automatic fuel feeding system using fuel-level sensors. The system includes an infrared (IR) level sensor, a controller unit having a micro controller, relay and power supply cards, and the control panel with contactors and fuses. The IR sensor consists of an emitter and a receiver. The detailed working procedure of the automatic fuel feeding system is given in the final report on the development of a large-capacity gasifier for agricultural residue briquettes submitted by SPRERI [2].

2.2. Scaled-up 375 kg h^{-1} modular down-draft gasifier

Based on the results of the 125 kg h^{-1} gasifier, a scaled-up modular gasifier capable of converting 375 kg h^{-1} was designed and tested at SPRERI. The system has a rectangular throat, hopper, manual ash removal unit, producer gas burner and belt conveyor for feeding briquettes to the gasifier hopper. Technical specifications of the system and burner are given in Table 1.

A 2 mm thick stainless steel sheet (SS 304) for the hopper and a stainless steel sheet (SS 310), 5 mm thick, was used for fabricating the combustion and reduction zone [2]. The hearth area (0.20 m^2) is designed for a specific gasification rate of $1.85 \text{ Mg m}^{-2} \text{ h}^{-1}$ and a fuel input rate of 375 kg h^{-1} . The 375 kg h^{-1} was scaled-up by adding three modules having dimensions of $260 \text{ mm} \times 260 \text{ mm}$ in series, thus the throat is made rectangular (size $260 \text{ mm} \times 780 \text{ mm}$). The other dimensions of the throat are as per the Imbert design given by Reed [3]. The comb-type hand-operated grate (see Fig. 2) worked after modifications, but jammed during operation, due to the

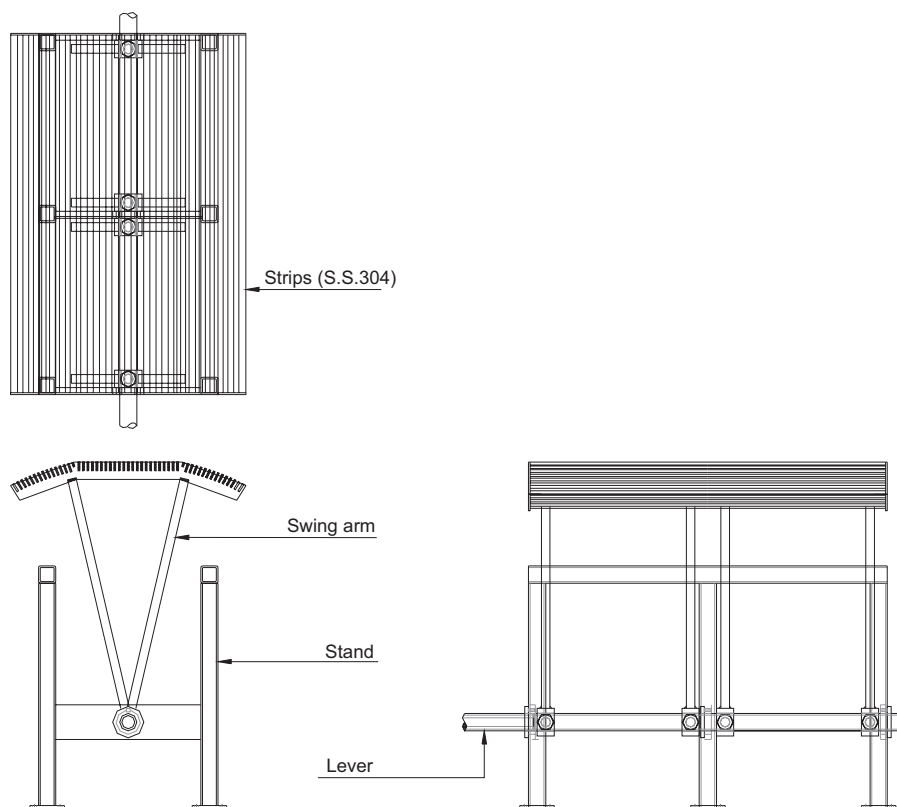


Fig. 3 – Schematic diagram of semicircular flat-type grate for a modular down-draft gasifier system.

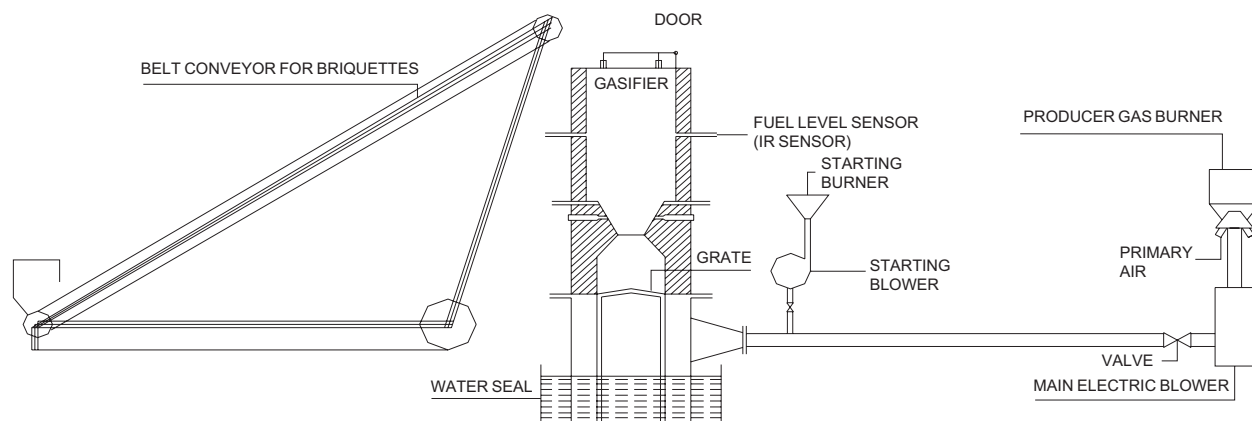


Fig. 4 – Schematic diagram of the 375 kg h⁻¹ modular throat-type down-draft gasifier system.

displacement of teeth. Finally, trials were taken with the teeth removed and a semi-circular flat-type grate was used (Fig. 3.) This was found to work satisfactorily, was easy to operate and was discharging ash easily.

In order to reduce heat losses, the hopper, the combustion and the reduction zones were insulated using cera wool of 150 mm thickness. In order to maintain uniform temperature in the combustion zone, 24 elliptical-shaped replaceable air nozzles made from stainless steel 310 were provided. The design capacity of the gasifier is 1000 Nm³ h⁻¹. The gasifier has a rectangular hopper and it has panels outside, which are convenient from the maintenance point of view as well as observation. A water seal is provided to prevent gas leakage. The gasifier is fabricated in three major parts:

1. Hopper
2. Combustion and reduction zone
3. Ash pit.

The schematic diagram of a modular down-draft gasifier is shown in Fig. 4.

2.2.1. Fuel feeding unit

A portable belt conveyor with a 0.75 kW motor was used to feed briquettes in the gasifier. The capacity of the conveyor was 8.0 t h⁻¹ of briquettes. It takes about 6 min to fill the gasifier hopper.

2.2.2. Ash removal unit

To remove ash from the gasifier, a comb-type hand-operated scraper to match the fixed grate was designed, fabricated and installed below the reduction zone. The grate was made of cast iron (grade 25) and had two units of 520 mm × 520 mm each. The stand for resting the grate was made of stainless steel 304. The spacing between the grate strips was 10 mm. There were 24 teeth to remove ash particles. The comb-type grate was not working properly and was later on replaced with a new design as described earlier.

2.2.3. Electric blower

A 3.75 kW centrifugal electric blower operating as an induced draft fan was used to operate the gasifier. Its impeller was

Table 2 – Properties of the briquettes and babul wood

	Biomass briquette	Babul wood
General		
Size: diameter (mm)	20	20–50
Length (mm)	30–80	20–80
Composition	60% Caster de-oiled cake+40% saw dust	–
Shape	Cylindrical	Cylindrical
Bulk density (kg m ⁻³)	606	407
Specific weight (kg m ⁻³)	1140	Not measured
Angle of repose (degree)	32.28	18.8
Proximate analysis		
Moisture content (%)	12.5	8.81
Volatile content (%)	56.8	83.23
Fixed carbon (%)	21.93	15.70
Ash content (%)	8.77	1.07
Calorific value (MJ kg ⁻¹)	17.28	16.82

made of stainless steel 304 to protect against high temperature, and it was of belt and pulley type with indirect drive.

2.2.4. Producer gas burner

A jet-type aerated burner was designed and developed [4]. It has the capacity to suck about 10–25% air through three air inlets from the surroundings as primary air, and secondary air from the atmosphere. Therefore, a separate electric blower for air is not required.

2.3. System operation

The system was operated on wood and briquettes (Table 2). Proximate analysis of wood and briquettes was carried out before the test by using the methods suggested by ASTM [5].

The detailed operating procedure of the gasifier is reported in the final report submitted by SPRERI [2]. The gasifier system was operated at different gas flow rates between 213 and

$460 \text{ Nm}^3 \text{ h}^{-1}$ and following parameters were measured during the experiment.

1. Fuel consumption rate by the topping-up method.
2. Gas flow rate by using a pitot tube.
3. Calorific value of the gas by using a Junker's gas calorimeter.
4. Temperature at the gasifier outlet, in different zones and flame temperature at the flare by using Chromel–Alumel (type K) and Pt–Pt, 13% rhodium (type R) thermocouples.
5. Pressure drop across the gasifier by using a U tube manometer.

Table 3 – Variation of calorific value of producer gas with time

Sr. no.	Time, p.m.	Calorific value (MJ Nm^{-3})
1	9.00	5.16
2	9.55	5.02
3	10.20	5.5
4	12.00	

Table 4 – Cold gas efficiency at different gas flow rate

Gas flow rate ($\text{Nm}^3 \text{ h}^{-1}$)	Cold gas efficiency (%)	Specific gasification rate ($\text{kg m}^{-2} \text{ h}^{-1}$)
213	73	439
278	69.5	602
460	70.5	893

3. Results and discussion

The instrumented experimental set-up was developed to carry out performance study of the system on flaring mode. Trials were carried out as follows:

3.1. Short-duration tests

The system was operated for a short-duration test of 4–5 h and the performance parameters mentioned above were measured. Table 3 shows that the calorific value of producer gas is almost constant throughout the experiment and it varies in the range of $5.0\text{--}5.5 \text{ MJ Nm}^{-3}$. Table 4 shows that cold gas efficiency and specific gasification rate vary in the range of 70–73% and $439\text{--}893 \text{ kg m}^{-2} \text{ h}^{-1}$, respectively.

3.2. Long-duration tests

The gasifier system was operated for a duration of more than 6 h on thermal mode, at a gas flow rate of $278 \text{ Nm}^3 \text{ h}^{-1}$ with a briquettes consumption rate of 122 kg h^{-1} . The various parameters described earlier were monitored during the trial. Fig. 5 indicates the temperature profile during the long-run test and shows that the temperatures are almost constant with time, which shows the stable operation of the gasifier system. Fig. 5 also indicates the variations in pressure drop across the gasifier, which shows that the pressure drop increases linearly with time, as grate was not moving during operation, which indicates the accumulation of ash on the grate.

The gasifier could not be operated at higher conversion rates due to the non-availability of suitable blower to handle higher flow rates of high-temperature gas.

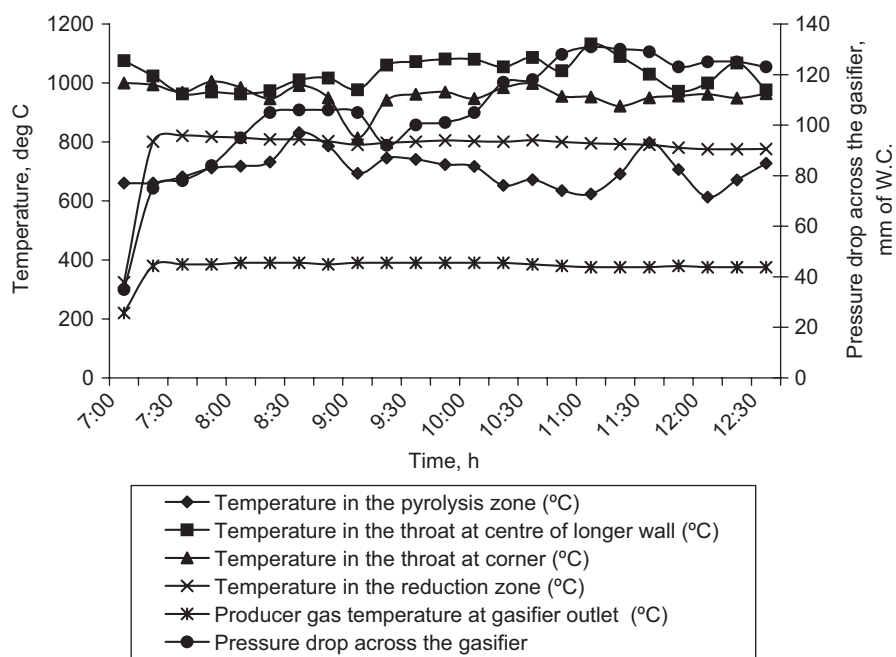


Fig. 5 – Variation of temperatures during a long-run test using briquettes.

4. Conclusions

The performance evaluation of the 125 kg h^{-1} modular down-draft gasifier shows that the concept of the modular design works satisfactorily, but the problems caused by uneven thermal expansion due to its rectangular throat have to be solved.

The scaled-up modular gasifier system has been successfully operated using agro-residue briquettes on a thermal mode at a gas flow rate of $278\text{ Nm}^3\text{ h}^{-1}$, with briquettes consumption of 122 kg h^{-1} . The cold gas efficiency was 70%.

The gasifier has also operated successfully using wood as feedstock at a gas flow rate of $460\text{ Nm}^3\text{ h}^{-1}$, with a wood consumption of 181 kg h^{-1} . The cold gas efficiency was 71%.

The overall performance in terms of consistency in production of good quality of gas was satisfactory. The average calorific value of the producer gas was 5.27 MJ Nm^{-3} for the large gasifier.

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